# Boiling Heat Transfer and Circulation Rate in a Thermosyphon Apparatus

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*Abstract* - **This study examines the boiling heat transfer and circulation rate characteristics in a Thermosyphon apparatus. For the test a Thermosyphon rig with the Reboiler (Evaporator section) and Condenser was used. The heat transfer section (Reboiler) contains a steam-heated stainless-steel rig/tube of 50mm diameter and height of 400mm with distilled water as the working fluid. The aspect height was maintained at 0.73m. It was found that when natural – circulation occurs in a thermosyphon apparatus, the heat transfers and circulation rates were highly dependent on the pressure and temperature difference.**

**The experimental results for operating pressures of 1bar (g) - 1.8bar (g) have shown data sets of Heat load values in the range of 828.7 – 2371 J/s, heat transfer coefficients values of 550 – 1221Wm-2K-1, temperature difference value 22 - 33oC and heat flux values of 13.2 – 37.6 KWm-1K-1.**

*Keywords:* **Boiling heat transfer Thermosyphon apparatus, Natural - circulation, Aspect height, Heat transfer Coefficient.**

## I. INTRODUCTION

A two-phase closed thermosyphon Reboiler is a high-performance heat transfer device used when a large amount of heat is to be transferred at a high rate when a small temperature difference is required. It's a closed loop filled with working fluid (distilled water). The heat transfer is obtained by the evaporation of the working fluid in the Reboiler (evaporator section).

The thermosyphon Reboiler is a closed vertical tube filled with working fluid (distilled water). Heat is supplied to the Reboiler via steam, which vaporizes the working fluid after some time. Vaporization at the surface of the working fluid occurs due to the heat absorbed by natural – convection from a hot rig beneath the surface. There is a transfer of heat from the Reboiler to the condenser in the form of latent heat of vaporization with a small temperature difference.

The two-phase closed thermosyphon apparatus that was worked upon consists of four major components:

The Reboiler (Evaporator)
The Rising tube
The Condenser
The Falling tube

## II. EXPERIMENTAL PROCEDURES

The following procedures were carried out on the thermosyphon apparatus to establish the objectives.

Before the start of the experiment, a test run was done on the thermosyphon apparatus to ensure that it's in proper working condition.

After the test run, the aspect height of the working fluid in the reboiler was established. The steam valve was opened to admit steam into the reboiler from the steam mains. The steam pressure was set to 1barg [Different steam pressure values were used].

Following the set-up of the steam and cooling water, the rig was allowed to reach a steady state before experimental run data were collected.

The cooling water flowing from the condenser was collected and measured with time in a measuring cylinder of 2 liters, and the volumetric flow rate was determined.

Collect and log in on logbook values of cooling water inlet and outlet temperatures;

Temperature value on the probe thermometer attached to the bottom of the evaporating column.

The temperature readings were taken at 1min intervals.

Rotameter readings [The Flow 1 and Flow 2] were taken at 10secs intervals.

Collect and weigh the steam condensate at 10-minute intervals. The experiment was repeated at various steam pressures (i.e., 1.2, 1.4, 1.6 bar g) and different working fluid aspect heights in the evaporating column. The system was allowed to reach state before new data were recorded. The information was used in conjunction with the reboiler/condenser temperatures to establish the result for the Research.
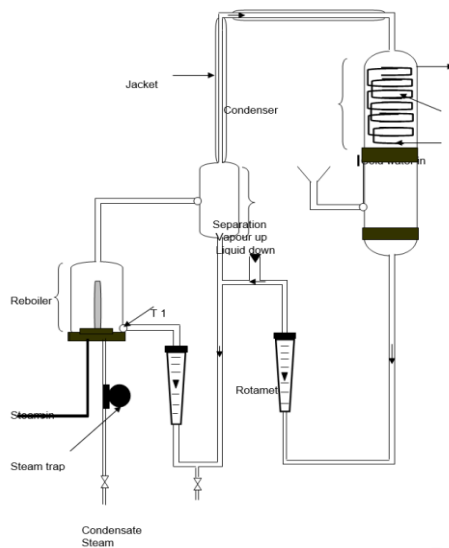
Fig. 1：Thermosyphon apparatus

### III.    RESULTS AND OBSERVATIONS
### A.   EXPERIMENTAL AND CALCULATED RESULTS

Table 1: Experimental and calculated data for Aspect height of 0.73m

| Aspect Height = 0.73m | | | | Steam pressure = 2.0bar a | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_R$ | $T_{in}$ | $T_{out}$ | FL $_1$ | FL $_2$ | Latent Heat(L) | Mass Conde (C) | Heat Load(Q) | Area | Heat Coeff (U) | Heat Flux (F) | ΔT | Time |
| °C | °C | °C | L/hr | L/hr | KJ kg$^1$ | kg/s | W | m$^2$ | W/m$^2$°C | KWm$^2$ | °C | (sec) |
| 98.0 | 18.5 | 39.5 | 1.5 | 1.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 592.52 | 13.50 | 22 .2 | 0 |
| 96.5 | 18.5 | 42.0 | 1.0 | 1.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 555.02 | 13.50 | 23.7 | 60 |
| 98.0 | 18.5 | 42.0 | 0.9 | 2.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 592.52 | 13.50 | 22 .2 | 120 |
| 96.5 | 19.0 | 41.0 | 1.0 | 1.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 555.02 | 13.50 | 23.7 | 180 |
| 93.5 | 18.5 | 41.5 | 1.0 | 1.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 492.66 | 13.50 | 26.7 | 240 |
| 100.0 | 19.0 | 41.0 | 1.2 | 1.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 651.19 | 13.50 | 20.2 | 300 |
| 98.0 | 18.5 | 42.5 | 1.4 | 1.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 592.52 | 13.50 | 22 .2 | 360 |
| 99.0 | 19.5 | 41.0 | 1.5 | 6.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 620.47 | 13.50 | 21.2 | 420 |
| 97.0 | 17.0 | 43.0 | 1.4 | 1.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 566.98 | 13.50 | 23.2 | 480 |
| 103.0 | 17.0 | 44.0 | 1.5 | 1.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 764.77 | 13.50 | 17.2 | 540 |
| 100.5 | 17.0 | 42.0 | 1.3 | 1.0 | 2202.0 | 3.67E-04 | 828.7 | 0.063 | 667.71 | 13.50 | 19.7 | 600 |
| Aspect Height = 0.73m | | | | Steam pressure = 2.2bar a | | | | | | | | |
| 100.0 | 11.0 | 14.5 | 1.5 | 1.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 695.28 | 16.2 | 23.3 | 0 |
| 102.0 | 11.5 | 14.5 | 1.0 | 4.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 760.56 | 16.2 | 21.3 | 60 |
| 97.0 | 11.0 | 14.5 | 1.5 | 4.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 615.97 | 16.2 | 26.3 | 120 |
| 100.0 | 11.0 | 15.0 | 2.0 | 6.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 695.28 | 16.2 | 23.3 | 180 |
| 90.0 | 11.0 | 14.5 | 1.8 | 1.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 486.49 | 16.2 | 33.3 | 240 |
| 98.0 | 11.5 | 15.0 | 2.2 | 2.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 640.32 | 16.2 | 25.3 | 300 |
| 101.0 | 11.0 | 14.5 | 1.0 | 4.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 726.46 | 16.2 | 22.3 | 360 |
| 98.0 | 11.0 | 14.5 | 2.0 | 10.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 640.32 | 16.2 | 25.3 | 420 |
| 98.0 | 11.0 | 14.0 | 1.5 | 10.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 640.32 | 16.2 | 25.3 | 480 |
| 100.0 | 11.0 | 14.0 | 1.5 | 10.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 695.28 | 16.2 | 23.3 | 540 |
| 90.0 | 11.5 | 13.5 | 2.0 | 22.0 | 2193 | 1.17E-03 | 1020.6 | 0.063 | 486.49 | 16.2 | 33.3 | 600 |

| *Aspect Height = 0.73m* | *Steam pressure = 2.4bar a* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99.0 | 11.0 | 16.0 | 2.0 | 40.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 948.22 | 25.7 | 27.1 | 0 |
| 99.0 | 11.0 | 16.0 | 0.5 | 46.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 948.22 | 25.7 | 27.1 | 60 |
| 99.0 | 10.5 | 16.0 | 3.5 | 38.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 948.22 | 25.7 | 27.1 | 120 |
| 98.0 | 11.0 | 17.0 | 1.5 | 40.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 914.48 | 25.7 | 28.1 | 180 |
| 99.0 | 11.0 | 16.0 | 3.0 | 32.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 948.22 | 25.7 | 27.1 | 240 |
| 95.5 | 11.0 | 16.5 | 0.2 | 46.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 839.77 | 25.7 | 30.6 | 300 |
| 96.0 | 11.0 | 16.5 | 3.0 | 40.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 853.72 | 25.7 | 30.1 | 360 |
| 95.0 | 11.0 | 16.0 | 3.0 | 40.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 826.26 | 25.7 | 31.1 | 420 |
| 98.5 | 11.0 | 16.5 | 0.3 | 45.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 931.04 | 25.7 | 27.6 | 480 |
| 99.5 | 11.0 | 16.5 | 4.0 | 38.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 966.05 | 25.7 | 26.6 | 540 |
| 99.0 | 12.0 | 16.5 | 2.5 | 30.0 | 2185 | 1.5E-03 | 1618.9 | 0.063 | 948.22 | 25.7 | 27.1 | 600 |

Table 2: Average calculated values at aspect height of 0.73m

| Pressure (Bar a) | Heat load (W) | Heat flux (KWm$^{-2}$) | Overall heat transfer coefficient (Wm$^{-2\circ}$C$^{-1}$) | Rate of Circulation (m$^3$/s) | $\Delta T$ ($^\circ$C) |
|---|---|---|---|---|---|
| 2.0 | 828.70 | 13.50 | 604.70 | 6.12E-04 | 22.00 |
| 2.2 | 1020.60 | 16.20 | 643.90 | 1.90E-03 | 25.70 |
| 2.4 | 1618.90 | 25.70 | 915.70 | 1.03E-02 | 28.10 |

## B.   EVALUATIONS: HEAT LOAD

The heat load of the thermosyphon apparatus was calculated using three different methods. According to theory, it is expected to obtain the same result, but was not achieved from the experimental data due to different sources of error and disturbances that occurred

### Method 1

Q = Flow 1 × latent heat of vaporization of water at 1bar (absolute)

$FL_1 = 3.67 \times 10^{-04}$ kg/s

Latent heat of vaporization (from steam table) = 2258KJ/kg

$Q = 3.67 \times 10^{-04} \times 2258 \times 1000$

Q = 828.7 Watts

### Method 2

Q = m× Cp × ΔT

m = 5.193E-03kg/s

Cp = 4.219KJ/kg K

ΔT (Temperature difference between the cooling water) = 26.4

$Q = 5.193 \times 10^{-03} \times 4.219 \times 1000 \times 26.4$

Q = 578.4 Watts

### Method 3

Q = Mass flow rate of condensate(C) ×latent heat of vaporization at steam pressure

Mass flow rate = $8.33 \times 10^{-04}$kg/s

Latent heat of vaporization at 2bar (absolute) = 2202KJ/kg

$Q = 8.33E-04 \times 2202$

Q= 1834.3 Watts

For this research, the Q obtained from the first method will be accepted and used for other calculations because it's about the most accurate result.

The Q obtained from method 2 is smaller than that obtained from method 1 due to heat loss by convection; the apparatus set-up had the majority of the pipe uninsulated.

The Q obtained from method 3 is greater than in methods 1 & 2. This implies that the steam supplied is wet - steam, i.e., the pipe through which the steam travels is insulated; hence, some condensation has occurred in the pipe. This affects the accuracy of the condensate flow rate measured during the experiment because there is an existing condensate in the steam earlier. In turn, the heat load (Q) calculated using that in-accurate value would be inaccurate.

### Area of the heating ring
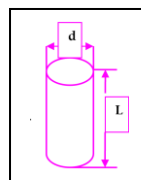


Area = π d L
d = 0.05m
L = 0.4 m
A = 3.142 × 0.05 × 0.4
A = **0.063 m$^2$**

## Heat flux

Heat flux = Q/A

Heat flux = 828.7 /0.063

Heat flux = 13.2 KWm$^{-2}$

Overall heat transfer Coefficient (U)

Q= U A ΔT

U = Q/A ΔT

U = 828.7 / (22.0 × 0.063)

U = 604.7 Wm$^{-2}$ $^{\circ}$C-1

Temperature difference (ΔT)

$\quad$ ΔT = T$_{steam\ pressure}$ − T$_{(avg)}$Reboiler unit

ΔT = (120.2 - 98.2) ºC

ΔT = 22.0ºC

## IV. RESULTS

The relationship between different parameters is shown in the graphs below.

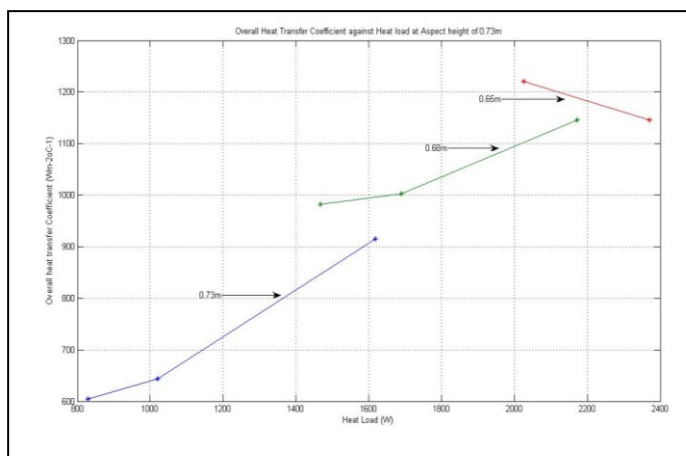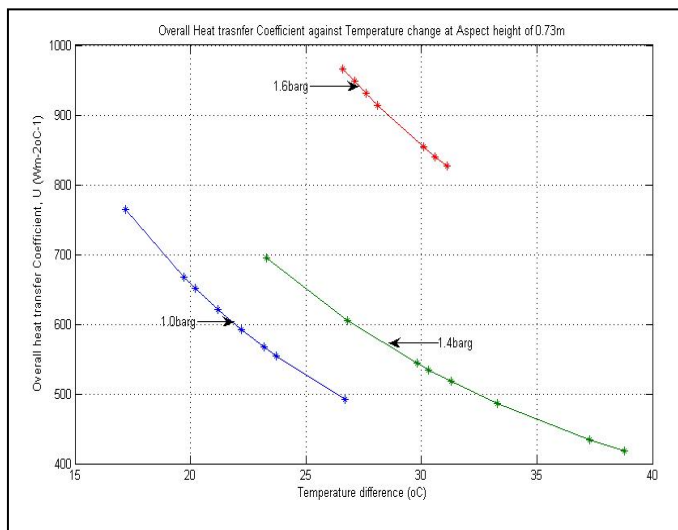**Fig 1**: **Overall heat transfer Coefficient against Temperature difference at Aspect height of 0.73m**





**Fig 2: Overall heat transfer coefficient (Wm$^{-2o}$C$^{-1}$) against Heat load (W)**

## V. DISCUSSIONS

### A. OVERALL HEAT TRANSFER COEFFICIENT

Overall heat transfer coefficients have been calculated according to the following equation:

$$U = \frac{Q}{\Delta TA}$$

Where U is the Overall heat transfer coefficient, ΔT is the temperature driving force and A is the area for heat transfer. In all cases Overall heat transfer coefficients continues to increase with heat load. It can be seen from the tables that the overall heat transfer coefficient is greater at higher steam pressure. Researchers attribute the influence of operating pressure on the overall heat transfer coefficient to a decrease in the reboiler sub-cooled heating zone and subsequent increase in the two-phase evaporating zone (i.e. increase in vapour generation) where overall heat transfer coefficient are greater at higher pressures.

The boiling phenomenon in Chemical industries is preferred because of its excellent heat transfer ability.

Figures 1 and 2 above relate the overall heat transfer coefficient to the temperature difference (driving force). It can be seen from the graphs that the overall heat transfer coefficient decreases linearly as the temperature difference (driving force) increases. We obtained the highest Overall heat transfer coefficient at the smallest temperature difference, which is in correlation with the general principle of a two-phase thermosyphon reboiler.

It can be seen from tables 1 and 2 that the overall heat transfer coefficient increases with increasing heat flux indicating the dominance of nucleate boiling.

As discussed above Overall heat transfer coefficient is strongly dependent on the heat flux and pressure and weakly dependent on Vapour fraction and mass flow, indicating that the nucleate boiling is the dominant mechanism.

## VI. CONCLUSIONS

In this study, the boiling heat transfer in a thermosyphon apparatus and relationship to the liquid circulation was investigated, several tests were performed and the results compared with the existing results. The conclusions from the present study are as follows.

The temperature distribution along the thermosyphon wall in the evaporator section was almost isothermal. The measured temperature along the condenser showed lower values. This drop of temperature is expected because of the internal resistances due to boiling and condensation.

The rate of circulation is affected by the heat transfer coefficient, hence at higher heat transfer coefficient it is expected to have a higher circulation rate also which fulfils our objective for this study.

Boiling heat transfer is most preferred in chemical industry because it offers a better heat transfer.

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